Laser spectrum line shape metrology at 193 nm

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ABSTRACT

The spectral shape requirements for an ArF laser for 193nm microlithography are expected to be about 2X tighter than at 248nm. This is in part due to the dispersion of fused silica and CaF_2 at 193nm and in part due to the push by the lens designers towards higher NA lenses. However, unlike 248nm, it is likely that the process engineer may not be satisfied with simple spectral bandwidth measurements of Full-Width-At-Half-Maximum (FWHM). Instead, the knowledge of the complete spectral shape may be required, since it is the total shape that has an impact on the lens performance. This requirement may have significant impact on corresponding metrology tools. These tools should be either portable or built into the laser. They should be able to provide continuos feedback to the process engineer as far as the lens performance is considered. Present paper discusses recent developments in 193 nm metrology which can be implemented as a part of laser on-board diagnostics or as a field service tool, and is capable of accurately measuring the laser spectrum shape. This information, together with proprietary lens parameters, will allow process engineer to accurately evaluate the aberrations due to the laser line shape.

Keywords: ArF laser, 193nm microlithography, metrology, spectrum

1. INTRODUCTION

Currently, ArF lithography at 193nm is moving from research labs into production. It is expected to become a main production lithography tool for 0.13 – 0.15 μm and below. The spectral shape requirements of an ArF laser for 193nm microlithography are expected to be about 2X tighter than at 248nm. This is in part due to higher dispersion of fused silica and CaF_2 at 193nm and in part due to the push by the lens designers towards higher NA lenses. This is especially true for all fused silica lens or for the lens with a limited chromatic correction[1]. Current production KrF laser typically has onboard diagnostics, which measures spectrum width at its Full-Width-At-Half-Maximum (FWHM) level. Because of increased sensitivity to the laser spectrum, this might not be enough for ArF lithography. Instead, the knowledge of complete spectral shape might be required. As a single number which can be used to characterize the shape, a spectrum width containing 95% of the laser pulse energy ($\Delta\lambda_{I95\%}$) can be used. Currently, ArF lasers with spectral bandwidth with $\Delta\lambda_{FWHM} < 0.6$pm and 95% integrated energy ($\Delta\lambda_{I95\%}$) within 1.5pm are available, but lasers with much narrower bandwidth will be required for high NA lenses. It will be desired, therefore, to have a capability of constantly monitoring both $\Delta\lambda_{FWHM}$ and $\Delta\lambda_{I95\%}$ during chip manufacturing, so that any problem with the laser can be immediately identified before it becomes too costly. On the other side, if the laser spectrum line shape is available, the process engineer can input his proprietary lens parameters in order to evaluate chromatic aberrations and image blurring due to the laser during chip manufacturing.

Currently available lithography excimer lasers generally have onboard etalon-based spectrometers, which are capable of continuously measuring and reporting bandwidth as well as the central laser wavelength. The problem, however, is that these spectrometers are generally good only for $\Delta\lambda_{FWHM}$ measurements and not for $\Delta\lambda_{I95\%}$ or actual spectrum shape measurements. Etalon spectrometer has relatively low contrast of its slit function[2] and it would be difficult to use it to accurately measure tails of the spectrum, where the light intensity is relatively low. In fact, the etalon slit function never goes to zero at any distance away from the peak position. Instead it levels off at some baseline background level, which can be as small as 0.1% in

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good etalons, but can potentially be up to 1% or even more. Therefore, when the laser spectrum is measured with the etalon spectrometer, the measured signal never goes below that baseline. On the other hand, $\Delta\lambda_{I95\%}$ definition is very sensitive to the tails of the spectral peak, where the signal can be as small as 0.1% of the maximum level. These levels are of the same order or even smaller than the etalon baseline level which makes $\Delta\lambda_{I95\%}$ measurements difficult, requiring heavy deconvolution. In order to be able to do accurate $\Delta\lambda_{I95\%}$ measurement without significant deconvolution, the contrast of spectrometer slit function as well as its signal-to-noise ratio should be significantly better than 1000:1 and preferably better than 10000:1.

In order to achieve such a high accuracy of spectral measurements, a high resolution grating spectrometer can be used. Unlike the etalon, a good quality grating allows one to achieve a very high optical contrast ratio of the slit function[3] . Most of the error in this case comes from the data acquisition electronics as well as from stray light inside the spectrometer. Unfortunately, these instruments are bulky, expensive, and very delicate to use. Therefore, it is difficult to have them built into the laser as a on-board diagnostics tool.

Another way to improve contrast of the slit function is to use a double pass etalon spectrometer. In paper[4] we discussed use of such an instrument for KrF excimer laser. This double pass spectrometer, while providing high optical contrast of the slit function, comparable to that of grating spectrometer, has a number of advantages over diffraction grating based spectrometer, such as smaller size and cost, and better stability. This kind of spectrometer can be implemented as an onboard laser diagnostic.

Another important issue when dealing with fast data acquisition is a noise problem. Even though there are precision spectroscopic PDAs available with a relatively low noise level, those PDAs are too slow to use for ArF laser diagnostics. A typical noise level of fast PDAs, however, can be about 1% of the full scale, which is too much for shot-to-shot $\Delta\lambda_{I95\%}$ measurements. Even though the random noise can be reduced by averaging, there might be system errors, which are not. For example, the response of each individual photodiode element of a PDA might vary a little bit. In order to reduce effect of this kind of error, special method of data acquisition has been developed, which is also discussed in the paper.

2. SPECTRAL MEASUREMENTS WITH HIGH RESOLUTION GRATING SPECTROMETER

To accurately measure laser spectrum in laboratory conditions, a high-resolution diffraction grating spectrometer can be used. There are a number of particular schemes that can be used. Usually, it is quite difficult to achieve the required 0.1 pm resolution at FWHM level using just a single pass grating spectrometer. Therefore, multi-pass (and multi-grating) approach is often chosen. Fig. 1 shows an example of such a double pass single grating spectrometer.

In this instrument, a sample of laser beam is focused by a lens onto a diffuser. The scattered light is directed onto the entrance slit of the instrument, which has a width of about 5μm. Light transmitted through the slit is collimated by a collimating lens. The collimated beam illuminates a diffraction grating, which is arranged in a near Littrow configuration. The light, reflected from the grating is reflected by a partial mirror back to the grating for the second pass. This second reflection off of the grating is focused by the collimating lens back to a line. Because this light is reflected at a small angle relative to direction of the incoming beam, a small mirror can be used to pick up the reflected light. An imaging lens can be used to magnify the slit image and transfer it onto a photomultiplier (PMT) readout box, which has another slit installed in front of it. Instead of a PMT and slit, a photodiode array (PDA) can be used for a "snap" acquisition of complete spectrum. The signal from PMT or PDA is read by a portable computer, which, in case of PMT also scans the slit to acquire complete spectrum. This scheme allows achieving the multi-pass configuration on a single grating in a relatively simple and compact way. The disadvantage of this scheme, is its relatively low throughput transmission because of losses caused by partial mirror. This, however, is not a big disadvantage, because there is usually plenty of light available for these measurements
In the Littow configuration, the dispersion of diffraction grating is determined by

$$d\beta / d\lambda = m / (d_g \cos\beta), \quad (1)$$

where β is the incidence angle, d_g is the groove spacing, and m is the diffraction order. The best resolution can be achieved when using echelle gratings working at high angles and high diffraction orders. For the same angle of incidence, the dispersion is reduced if grating is used in off-Littrow configuration with the diffraction angle smaller than the incidence angle. The spectrometer shown in Fig.1 uses near Littrow conditions on both passes, so it provides about twice the dispersion of a single-pass spectrometer. Of course, the actual resolution of the instrument would greatly depend on quality and flatness of optical components used. If required, this spectrometer can be used in triple (or even higher) pass configuration by properly aligning partial reflector and allowing the beam bounce several times between the grating and the partial reflector, although the signal level will drop significantly due to high losses caused by partial reflector and grating.

This type of grating spectrometers provides high resolution adequate for both $\Delta\lambda_{FWHM}$ and $\Delta\lambda_{I95\%}$ measurements. Fig. 2 shows a slit function of the instrument built by Cymer, Inc. using an optical scheme similar to that of Fig. 1. Fig.2 shows a typical spectrum of current production ArF laser and a spectrum of next generation ultra-narrow ArF laser. It also shows the grating spectrometer slit function, which has been measured by line-narrowing the spectrum of ArF laser with an external high-finesse etalon. The grating spectrometer provides enough resolution for accurate measurements of $\Delta\lambda_{FWHM}$ and $\Delta\lambda_{I95\%}$ for both current and next generation ArF lasers. The measured $\Delta\lambda_{I95\%}$ of the slit function is probably artificially increased by a finite bandwidth of externally line-narrowed 193 nm calibration source.

Unfortunately, high-resolution grating spectrometers tend to be quite bulky and difficult to incorporate into the laser. The main size factors are the big focal length of the collimating lens as well as the size of the grating(s) itself. Reduction of the size presents a real technical challenge. Cymer Inc. was able to reduce the size of these spectrometers to about 900 x 300 x 250 mm without sacrificing the resolution. Even though this is still too big to be installed in the laser permanently, it does allow using this instrument as a field service diagnostic tool.

3. ETALON FABRI-PEROT FOR ONBOARD LASER SPECTRAL DIAGNOSTICS

Because of the size of the grating spectrometers, a typical lithography excimer laser now has an onboard etalon Fabri-Perot based spectrometer. Fig. 3 shows a typical etalon spectrometer used for linewidth measurements. The sample of the laser beam goes through a diffuser and then illuminates an etalon. Usually, the air spaced etalon is used, with the etalon plates coated to reflect about 90 - 95% of light. The transmitted light through the etalon is collected by a lens and focused onto a PDA array, where a set of fringes is formed. The signal from the PDA is read by a laser microprocessor. The intensity of transmitted light along the angle α to the etalon is determined by the following equations[5]:

$$I_t = I_0 / (1 + (2F/\pi)^2 \sin^2 (\delta /2)) , \quad (2)$$

$$F = \pi R^{1/2} / (1 - R) , \quad (3)$$

$$\delta = 2\pi \Delta s / \lambda + \Delta\phi , \quad (4)$$

$$\Delta s = 2dn_a \cos\alpha. \quad (5)$$

In these equations, I_0 is the incident light intensity, δ is the phase shift, $\Delta\phi$ is extra phase shift on reflection from the etalon surface, λ is the laser wavelength, d is the etalon gap, F is the etalon finesse, n_a is the

refractive index of gas filing the gap, and α is the incident angle. As a result, a set of concentric fringes is formed with radii satisfying equations (2) - (5). The spacing between the fringes is determined by an etalon FSR value:

$$FSR = \lambda^2 / 2nd. \quad (6)$$

By proper choice of FSR and etalon finesse (F), accurate measurements of laser spectral bandwidth at FWHM level can be done. Unfortunately, this etalon spectrometer is not a very good tool to measure the spectrum shape, in particular, to accurately measure the spectrum tails. This is because the slit function of the etalon spectrometer as described by eqs. (2) - (5) does not provide enough resolution for the measurement of the tails of the laser spectrum.

Fig. 4 shows a calculated slit function of the etalon spectrometer as well as the spectrum of next generation ArF laser measured with a high resolution grating spectrometer. The etalon spectrometer has FSR = 5 pm, and F = 38. The etalon spectrometer slit function has $\Delta\lambda_{FWHM}$ = 0.13 pm, which can be sufficient for accurate spectral measurements on FWHM level. Unfortunately, accuracy of the spectrometer drops significantly at the tails of the spectrum. In fact, one can see, that at the tails of the spectrum the slit function curve is actually gets above the laser spectrum curve. That means, it would be very difficult to use this spectrometer to accurately measure laser shape in these areas. This is also reflected by the fact, that $\Delta\lambda_{I95\%}$ of the etalon spectrometer slit function is about two times larger than $\Delta\lambda_{I95\%}$ of the laser spectrum. In order to get $\Delta\lambda_{I95\%}$ value out of etalon spectrometer measurements, some kind of deconvolution is required. There may be several ways to do this deconvolution. The most accurate way is to do correct mathematical deconvolution of measured spectrum function using the etalon spectrometer slit function. This can be done based on Fourier transform. Unfortunately, this is a very CPU time-consuming process. Significant improvement in speed can be achieved by using fast Fourier transform based deconvolution. This reduces the calculation time to typically a second or less. For lithography purposes, it might be interesting to have information on average spectrum over an exposure window, which typically takes about 50 laser pulses at 2000 Hz. The fast Fourier transform based deconvolution would be too slow for such a rate. The next level of simplification is to use a look-up correction table to do a shot-to-shot deconvolution. The lookup table is determined individually for each etalon during laser manufacturing. One particular case of a look-up table is subtracting a constant value from the raw readings. If properly calibrated, these lookup tables might provide reasonable deconvolution accuracy when the laser is running properly and its spectrum shape is fairly predictable. The problem is, however, that these lookup tables might not work very well when the laser goes out of spec. Laser can go out of spec for a variety of reasons, which can change the shape of the spectrum line in a variety of ways. It might not be possible to correctly account for all these changes in the lookup table. Unfortunately, this is the time when the accuracy of the etalon spectrometer deconvolution is most needed.

It should be pointed however, that all this discussion relates to $\Delta\lambda_{I95\%}$ measurements. As far as $\Delta\lambda_{FWHM}$ is concerned, even simple subtraction of a constant value works reasonably well.

4. ETALON SPECTROMETER RESPONSE FOR DIFFERENT LASER SPECTRUMS

Despite all the problems associated with the etalon spectrometers, they are currently the ones used to measure laser spectrum during chip manufacturing. So, there always will be a drive to use them for measuring laser shape as well as FWHM. In this chapter we will discuss the accuracy of these measurements by analyzing the results of numerical simulation of the etalon spectrometer response to different laser spectrums. In all the calculations in this chapter we will assume that the PDA has an element size of 14 microns and is placed in the focal spot of 1m lens.

The simulation procedure is as follows:

1. Calculate etalon fringes for the input laser spectrum using (2) – (5)

2. Calculate total intensity for each pixel of a PDA, that is, calculate function I(i), where i is pixel number, and I(i) is total light intensity incident on pixel i
3. Convert I(i) into I(λ)
4. Calculate FWHM and I95% of I(λ).

Fig. 5 shows an input laser spectrum we used, which has $\Delta\lambda_{FWHM} = 0.368$ pm and $\Delta\lambda_{I95\%} = 1.49$ pm, as well as calculated response of an etalon spectrometer. From the zoomed portion of Fig. 5 one can see that there is a baseline in etalon measured spectrum due to limited contrast of etalon slit function. This baseline is about 0.2% for finesse of 60 used in these calculations. It should be pointed out that finesse of 60 is a fairly high finesse value. A typical etalon spectrometer would likely have somewhat lower finesse, so that the baseline would be correspondingly higher. The big question is, how to correctly measure this baseline. The problem is complicated by the fact that the signal is measured with a PDA. These PDAs, especially, the fast ones, which are necessary for shot-to-shot measurements, tend to have a significant dark current that can be up to several percent of the maximum signal. Accurate separation of the optical baseline signal from the electronic dark curent of the PDA itself does present a big technical challenge. One of the ways to solve this problem will be discussed in the next chapter. For our discussion in this chapter we will assume two different cases. In the first one, the optical baseline is separated from the dark current, and is therefore, correctly measured. We will refer to this case as 'baseline preserved'. In the second case, a more simplified approach is simulated, in which a signal (optical baseline plus electrical dark current) at the ends of measurement range are assumed to be zero. This approach is easy to realize technically, but it removes the information on optical baseline. We will refer to this case as a 'baseline subtracted'.

For the next simulation we will use several input laser spectrum curves which all have the same $\Delta\lambda_{FWHM} = 0.368$ pm, but different $\Delta\lambda_{I95\%}$ values ranging from 1.15 pm to 2.7 pm. In other words, these spectrums will be different in the shape of their tails but would have the same shape and width of the central peak as shown in Fig. 6. Fig. 7 shows results of simulations of the etalon spectrometer response to these different spectrums. One can see that the FWHM measurements are pretty consistent for all the spectrums. They can be defined by a simple formula:

$$\Delta\lambda^{m}_{FWHM} = \Delta\lambda^{o}_{FWHM} + C, \quad (7)$$

where $\Delta\lambda^{o}_{FWHM}$ is the bandwidth of original spectrum, $\Delta\lambda^{m}_{FWHM}$ is the simulated measured spectral bandwidth, and C is a constant value, which can be measured during laser manufacturing. From Fig. 7 one can see, that C is slightly less than FSR / F. In case of exactly lorentian laser spectrum shape, C would be exactly FSR / F. The situation is very different for $\Delta\lambda_{I95\%}$, though. Here we have two very different results, depending on whether or not baseline subtraction was done. Also, in both cases, the simulated measured results deviate significantly from the original spectrum, and there is no simple linear relationship between them. In 'baseline subtracted' case, while the spectrometer is measuring higher raw $\Delta\lambda_{I95\%}$ values than the real ones for relatively small $\Delta\lambda_{I95\%}$ (which is quite reasonable), it can measure lower raw $\Delta\lambda_{I95\%}$ values than the real ones as $\Delta\lambda_{I95\%}$ values of the input spectrum grows. This is, in fact, potentially a pretty dangerous situation in the field because this happens when the laser actually goes out of spec and at that time the etalon spectrometer would underestimate the readings. As a result, the laser might report bandwidth in spec, but the real spectrum width might be already causing image blurring. Of course, this happens because optical baseline was artificially removed. When no baseline subtraction is done, the raw values are never smaller than the real ones. The situation is still quite complicated, however, because the dependence between real and measured spectrums is quite complex. It might present a technical challenge to implement this as a lookup table.

Fig. 8 shows dependence of $\Delta\lambda_{FWHM}$ and $\Delta\lambda_{I95\%}$ readings on etalon FSR. In this case, the input spectrum has $\Delta\lambda_{FWHM} = 0.368$pm and $\Delta\lambda_{I95\%} = 1.49$pm. Finesse of the etalon is 60. One can see that with an exception of very small FSR, $\Delta\lambda_{FWHM}$ follows equation (7) quite good. In this case:

$$C = k \cdot \mathrm{FSR} / F, \quad (8)$$

where k is a constant k < 1.0. If k is assumed to be 1, than the error would be no more than 0.02pm. The situation is different for $\Delta\lambda_{I95\%}$ measurements. Again, at small FSR values baseline subtraction can actually produce raw measured values smaller than original ones. Also, the deviations of both 'baseline subtracted' as well as 'baseline preserved' measured values from the real ones is quite significant.

Of course, correctly done deconvolution should be able to produce the real spectrum from these measurements quite accurately, provided that few factors are met. First, the optical baseline has to be measured correctly. Ways to do it will be discussed later in the next session. Second, the etalon slit function has to be known precisely. It is relatively easy to measure slit function during manufacturing for every spectrometer built and program this slit function into the laser microprocessor memory to use for deconvolution. The problem is that this slit function can change over time. For example, when the etalon was new, the reflectivity of its surfaces was 95%, but over time under UV exposure it went down to 94%. It will reduce the reflectivity finesse of the etalon from about 60 to 50. The effect of this reduction on measurements is shown in Fig. 7 as a dashed line. In case of FWHM measurements, such reflectivity degradation will lead to overall uniform shift up by 0.025pm or about 6% of $\Delta\lambda_{FWHM}$ value for all the input spectrums. The shift for $\Delta\lambda_{I95\%}$ measurements is about 0.036pm or 2% for 'baseline subtracted' data, and about 0.1pm or 5% for 'baseline preserved' data. These are the kind of errors, which are probably acceptable. However, larger changes in etalon reflectivity will create larger errors, which might become a problem.

A way to improve the optical resolution of the etalon spectrometer is to make it double pass, as it was described in paper[4]. Fig. 9 shows the scheme of such a double pass etalon spectrometer. In this spectrometer, the light goes through the etalon twice, which leads to significantly increase of its contrast. In particular, the baseline goes down to less than 10^{-4}, so it becomes practically insignificant.

5. FAST DATA ACQUISITION USING PDAs

Typical KrF microlithography excimer laser currently runs at 1 – 2 kHz rep. rate and even higher rep. rates are likely to be used in the next generation ArF systems. In order to provide sufficient accuracy of measurements, PDAs having at least 1024 or, more preferably, 2048 elements should be used. That means, these PDAs should be capable of readout at the rate of 4 Mpixels/second or higher. Such fast PDAs are currently available but are quite noisy. The noise can be as high as 1 – 2 % of the maximum signal. The random noise can be reduced by averaging several pulses, because:

$$\delta I_{ave} = \delta I / \sqrt{N}, \tag{9}$$

where δI_{ave} is the noise of the averaged signal, δI is the noise of a single acquisition, and N is the number of averages. Therefore, in theory, the noise level can be reduced to negligible levels by sufficient averaging. At 2000 Hz, even averaging over 2000 pulses would take only 1 sec. It is desired, however, to have a data, which is an averaged spectrum over exposure window, which in case of a scanner is typically about 50 pulses. In this case the noise of averaged signal will be only $\sqrt{50} \sim 7$ times smaller than the noise of an individual acquisition. If the noise of a PDA is about 1%, this noise reduction by averaging might not be enough. The solution might be the averaging over the same exposure window in many subsequent bursts. This can be done on the assumption, that the repeatability of the spectrum from burst to burst is good, which is usually the case. This way, the random noise can be reduced to the required small values. In this approach, the $\Delta\lambda_{I95\%}$ spectrum update will be done periodically, say, once a second, but the acquisition is done of every laser pulse. It also should be noted, that less demanding $\Delta\lambda_{FWHM}$ value can be updated on a shot-to-shot basis, because it does not require averaging.

Much bigger problem, however, is in the fact, that the random noise is not the only error generated by the PDA. Another significant contributor to the error is due to an offset and dark current, which is slightly different for each individual pixel of the PDA. This will not go away by averaging, because this dark current does not change from pulse to pulse, and it will therefore be the same for all the pulses in the

averaging. The author's experience shows that the error caused by dark current is usually somewhat smaller than the random noise, and is typically, no more than 0.5 – 1% of the maximum signal. Nevertheless, this dark current has to be removed for accurate $\Delta\lambda_{I95\%}$ measurements.

There are two methods, which are typically used for dark current calibration. In the first one, the signal from unexposed elements is measured every time the PDA is read. This value is then used to calibrate all the pixels of the PDA for each scan. This technique allows real time calibration, but it assumes that dark current is the same for all the elements of the array. Unfortunately, this is not the case for fast PDAs. Therefore, this technique can not be used for $\Delta\lambda_{I95\%}$ measurements. In another technique, the dark current from each pixel of a PDA is measured when there is no light exposure, and is saved in computer memory. Later on, during the actual measurements, this data is used to calibrate each pixel individually. In this technique, in order to do dark current calibration, the laser has to be shut down, which means that this can not be done very often. Unfortunately, the dark current offset can change over time, sometimes as fast as in several minutes. That means that this technique is not suitable for microlithography applications as well.

The authors developed a new technique of dynamic dark current calibration, which can be done for every pulse of the laser and for every pixel of the PDA. It also does not require the laser to be shut down. This dynamic calibration allows to continuously measure the offset for each pixel without laser interruption. Fig. 10 compares laser spectrums, measured with standard dark current correction based on unexposed pixels, and the new dynamic correction technique. The reduction of noise is dramatic. Now, because the offset is corrected, the averaging of several pulses will reduce the noise in the acquisition system proportionally to $\sqrt{N}$, so that required accuracy can be achieved if N is big enough. Also, because dark current is now corrected, this new technique allows accurate measurement of the optical offset, so that accurate deconvolution of the single pass etalon spectrometer can now be done. If a double pass etalon spectrometer is used, this technique will allow accurate measurement of the spectrum without extra heavy deconvolution.

6. CONCLUSION

The presented results show that $\Delta\lambda_{I95\%}$ measurements (or other line-shape measurements) can be made part of laser diagnostics suite. The optical scheme can be based on an etalon spectrometer, either in single or double pass configuration. The double pass etalon spectrometer provides better accuracy and reliability of the results, and does not require heavy deconvolution. The single pass etalon spectrometer, while more simple, will require heavy deconvolution in order to get accurate $\Delta\lambda_{I95\%}$ measurements. This deconvolution, while being calculation demanding, also requires that the etalon parameters be very stable over the lifetime of the spectrometer. This might potentially present a technical challenge for production lasers. Another important part of the $\Delta\lambda_{I95\%}$ spectrometer is an accurate data acquisition. In particular, it is very important to reduce the noise and correctly subtract the dark current of fast PDAs. The presented method of dynamic dark current calibration allows such correction to be made continuously without interruption of the laser. Another potential problem, which might need to be addressed, is a long lifetime of these PDAs. This problem, however, generally falls beyond the scope of the laser manufacturer and has to be solved by the PDA manufacturer.

REFERENCES

1. J. Sheets, ed., *Microlithography: Science and Technology*, Marcel Dekker, NY, 1998.
2. J. R. Meyer-Arendt, *Introduction to Classical & Modern Optics*, Prentice Hall, Englewood Cliffs, 1989.
3. E.G.Loewen, E. Popov, *Diffraction Gratings and Applications*, Marcel Dekker, NY, 1997.
4. Ershov, G.G.Padmabandu, J.D.Tyler, P.P.Das, "Novel metrology for measuring spectral purity of KrF lasers for deep UV lithography", *Proc. SPIE*, **3677**, pp. 611 – 620.
5. W. Demtroder, *Laser Spectroscopy*, Springer-Verlag, NY, 1982

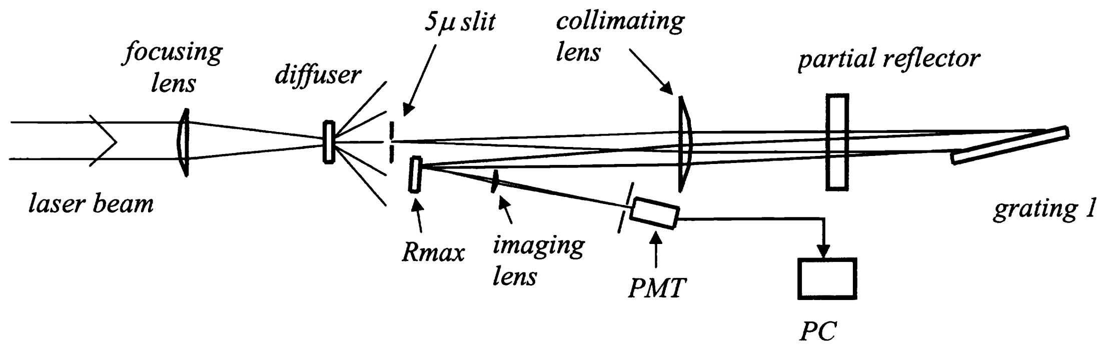

Fig. 1. High resolution multi-pass grating spectrometer.

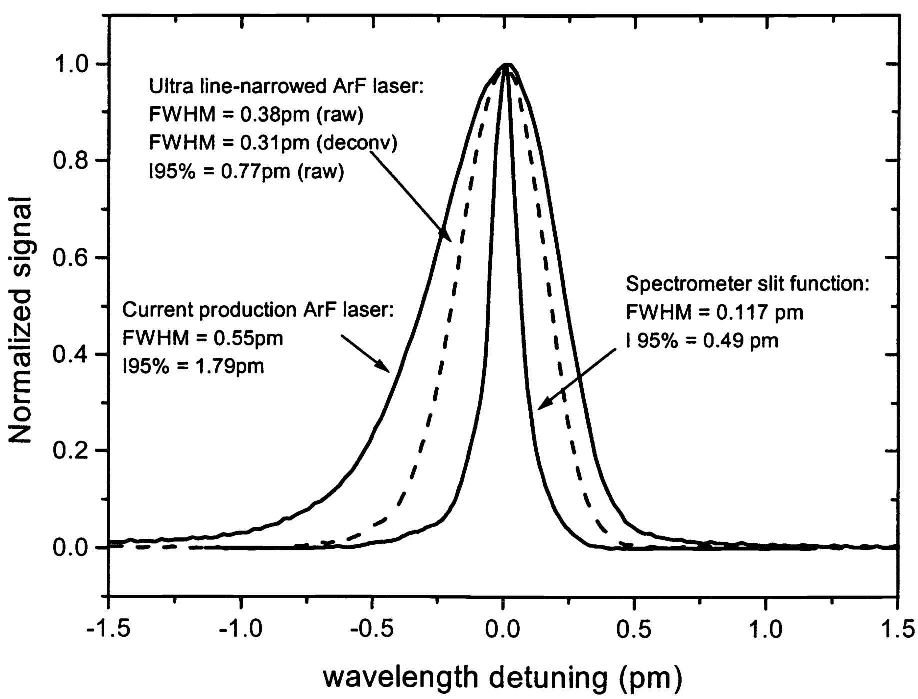

Fig.2. Spectrums of ArF excimer lasers as well as slit function of the high resolution grating spectrometer.

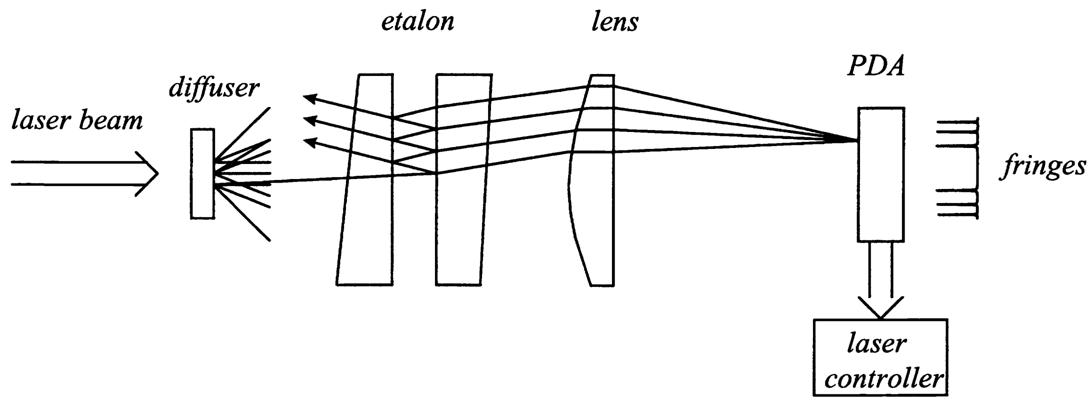

Fig. 3. Optical scheme of an etalon spectrometer currently used for onboard excimer laser diagnostic

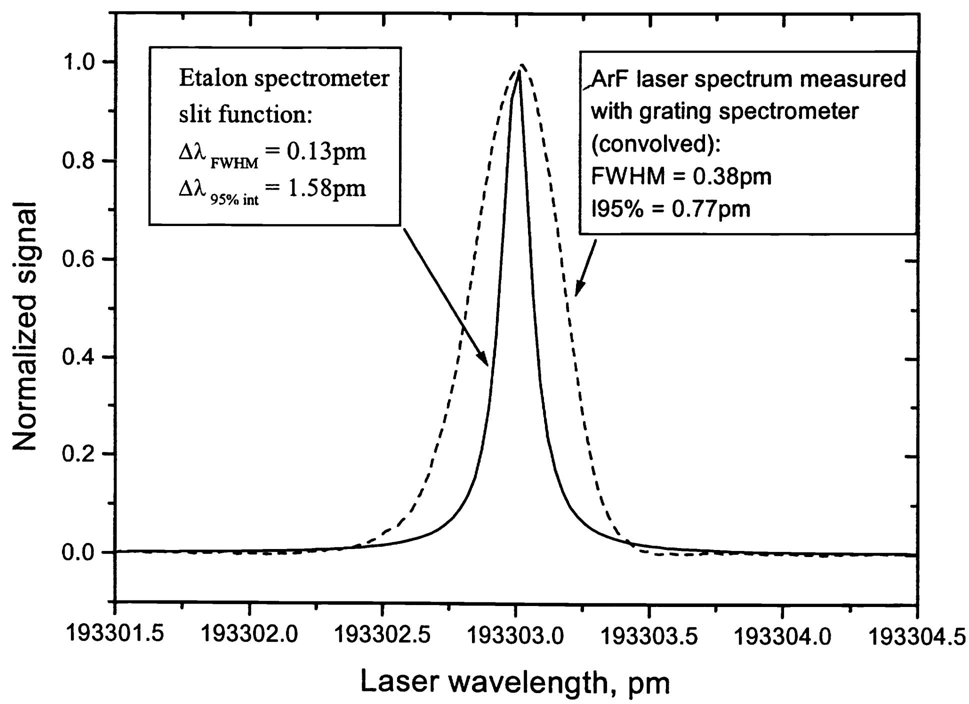

Fig. 4. Calculated etalon spectrometer slit function and ArF laser spectrum measured with a high resolution grating spectrometer.

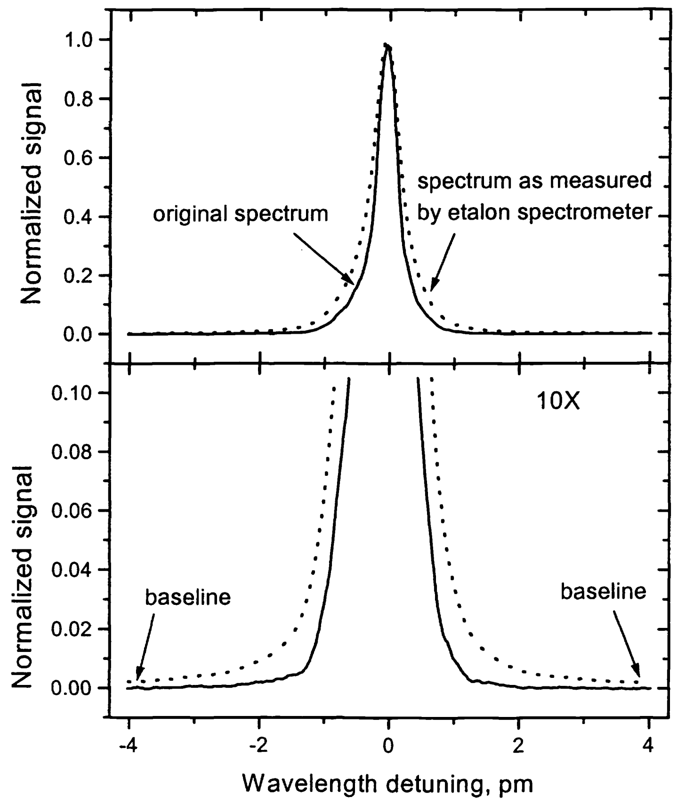

Fig. 5. Input laser spectrum ($\Delta\lambda_{FWHM}$ = 0.368 pm and $\Delta\lambda_{I95\%}$ = 1.49 pm) and simulated etalon measured spectrum.

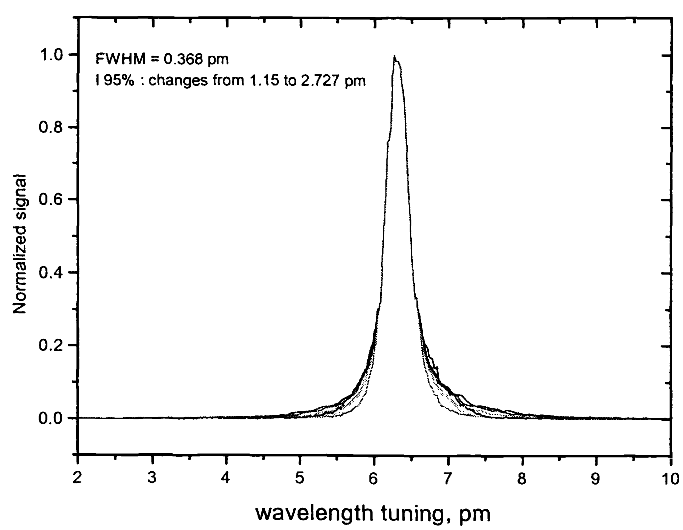

Fig. 6. Input laser spectrums used to simulate etalon spectrometer response. All spectrums have the same $\Delta\lambda_{FWHM}$ = 0.368 pm, but different $\Delta\lambda_{I95\%}$ ranging from 1.15 to 2.727 pm.

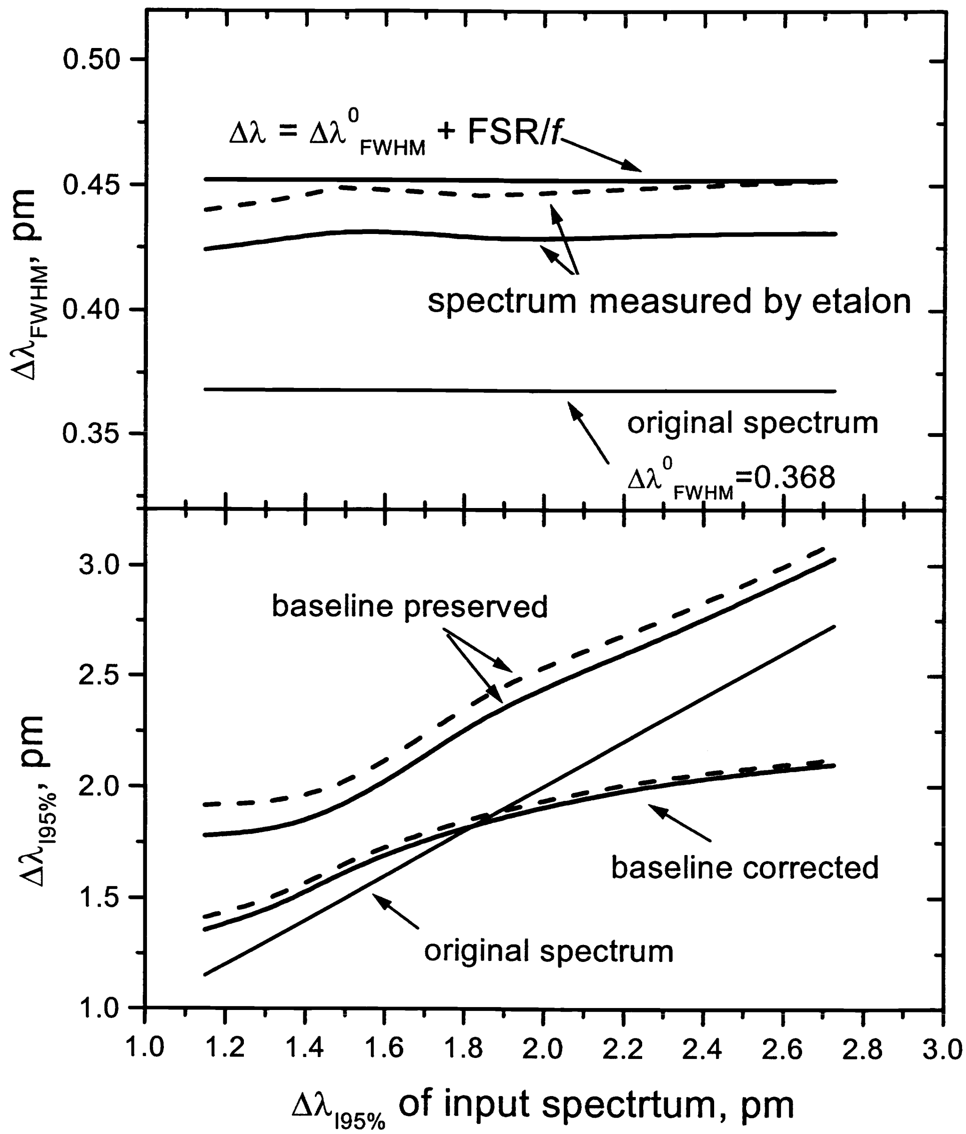

Fig. 7. Dependence of simulated etalon measured spectrum on input laser spectrum shape. All input laser spectrums have the same $\Delta\lambda = 0.368$ pm but different $\Delta\lambda_{I95\%}$ ranging from 1.15 pm to 2.7 pm. Solid line is the calculated etalon response for reflectivity of etalon surfaces of 95%. Dashed curves show change in the etalon response if the reflectivity drops to 94%.

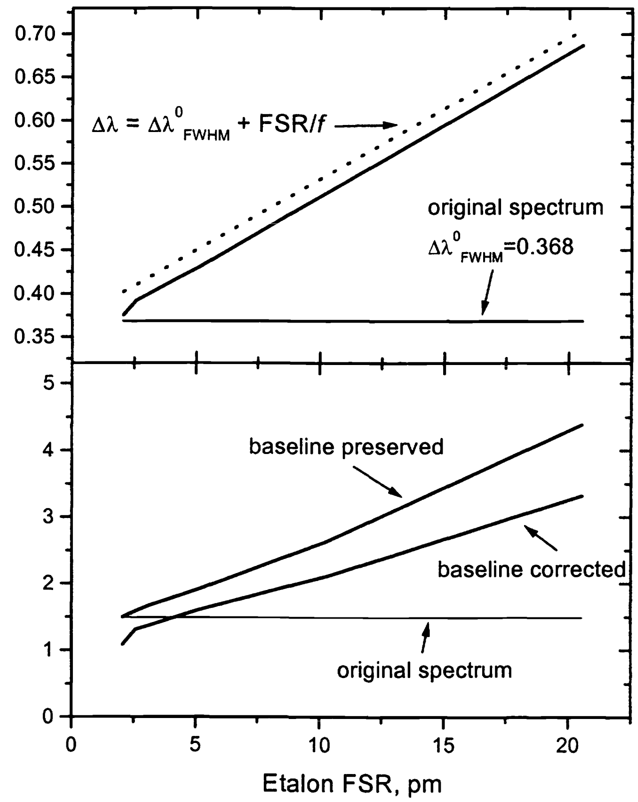

Fig. 8. Simulated etalon spectrum measurements for different etalon FSRs. Input laser spectrum has $\Delta\lambda$ = 0.368 pm and $\Delta\lambda_{I95\%}$ 1.49 pm. Etalon surfaces reflectivity is 95%, which corresponds to reflectivity finesse $f = 60$.

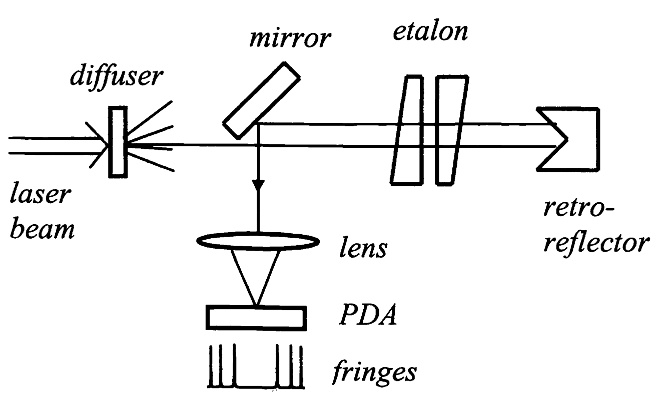

Fig. 9. Optical scheme of double-pass etalon spectrometer. Retro-reflector sends the beam back for the second pass through the etalon.

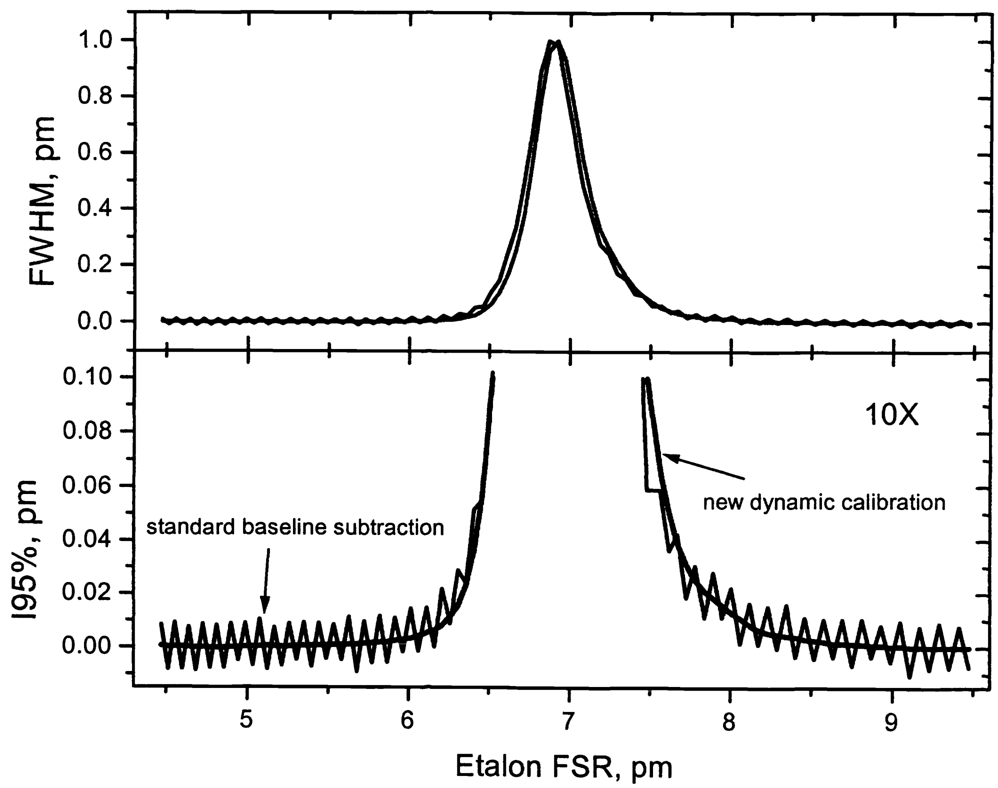

Fig. 10. ArF laser spectrum measured using standard baseline correction technique as well as new dynamic calibration scheme.